Simulation of CLARREO Ability to Calibrate Solar Reflectance Sensors in Orbit using High Spectral Resolution SCIAMACHY Data

Constantine Lukashin, SSAI, Hampton, VA Bruce A. Wielicki, NASA LaRC, Hampton, VA, Zhonghai Jin, SSAI, Hampton, VA
John P. Burows, Stefan Noel & Klaus Bramstedt, Bremen U, Bremen, Germany Ralph Snel, SRON, Utrecht, the Netherlands

1. CLARREO Inter-Calibration Goal

To be able to detect the anthropogenic radiative forcing of ~ 0.6 Wm^{-2} $decade^{-1}$ 50% change = 0.3 $Wm^{-2}decade^{-1}$ globally.
(IPCC Forth Assessment Report, the Physical Science Basis., 2007)

Relative to 50 Wm^{-2} (global average SW cloud radiative forcing) = 0.6%.

Reducing uncertainty to 25% would require stability of 0.3% $decade^{-1}$ for broadband *(Loeb et al., Multi-Instrument Comparison of TOA Reflected Solar Radiation, Journal of Climate, v.20, 2007)*.

CLARREO Goal: At least 0.2% (2σ) relative accuracy for SW broadband.

2. SCHIAMACHY High Resolution Spectral Data

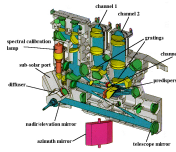


Figure 1. High resolution grating spectrometer SCIAMACHY. Optical arrangement of Level-1 hardware.

- ENVISAT SSP 10 am orbit, 800 km altitude.
- Level-1B spectral radiance data product, latest available calibration, January and July months for 2003 – 2007 time period.
- Footprint 30 km x 230 km, swath 950 km in 5 integrations.
- Global coverage in 3-4 days.
- Spectral range from 240 to 1750 nm wavelength is used.
- MODIS based Cloud and aerosol parameters from CERES/Terra SSF matched to SCIAMACHY footprints.

Channel	Spectral range (nm)	Spectral Resolution (nm)	Spectral Stability (nm)	Reflectance Errors (%)
1	240 - 314	0.24	0.003	3
2	309 - 404	0.26	0.003	2
3	392 - 605	0.44	0.004	3
4	598 - 790	0.48	0.005	2
5	776 - 1056	0.54	0.005	6
6	991 - 1750	1.48	0.015	4
7	1940 - 2040	0.22	0.003	Problems
8	2260 - 2384	0.26	0.003	Problems

Table 1. SCIAMACHY channels spectral ranges, resolution and uncertainties.

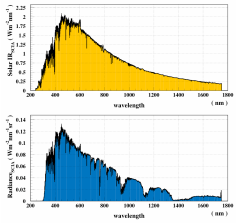


Figure 2. Example of SCIAMACHY data: daily solar irradiance and mean reflected nadir radiance spectra from 2006.07.01.

3. Simulation Parameters

- Offset – constant term of difference between sensor and CLARREO radiance, independent on wavelength, radiance units.
- Gain – linear term of difference, relative to CLARREO gain which is unity.
- Nominal RSR – sensor RSR as it is known.
- Simulated RSR – sensor RSR with degradation for broadband and CW shift for narrowband.
- Noise – combined random noise from time, space and angles mismatching, Gaussian distribution.
- Sampling – simulated CLARREO sampling for nadir-only and pointing capability matching.

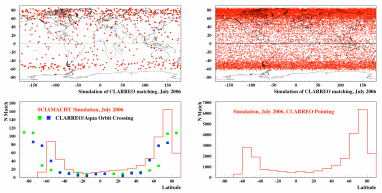


Figure 3. Sampling distributions for CLARREO matches with nadir-only (left, 665 footprints) and pointing matching ability (right, 23,435 footprints). Sampling increase in later case due to 40 cross-track angle/space/time matches per orbit crossing. SCIAMACHY data of July 2006 was used for simulation. CLARREO/Aqua orbit crossing simulation by Doelling and MacDonnel.

4. Simulation of CLARREO/CERES Calibration

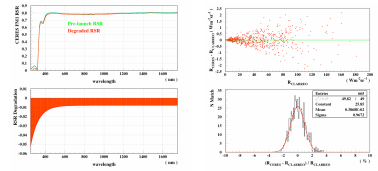
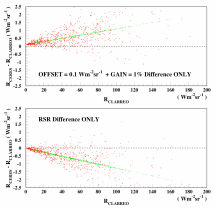


Figure 4. LEFT: CERES FM1 relative spectral response (RSR) function was used in simulation. The pre-launch and degraded versions are shown in green and red, respectively. The amount of degradation is shown in bottom left plot. RIGHT: Simulation of matching noise, random Gaussian distribution with σ = 1%

Offset = 0.1 $Wm^{-2}sr^{-1}$, Gain = 1%, Noise σ = 1%
CLARREO nadir-only sampling:



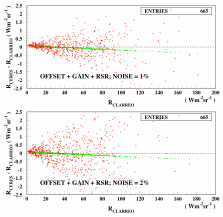
OFFSET + GAIN ONLY :	
OFFSET ($Wm^{-2}sr^{-1}$)	GAIN (%)
0.09 ± 0.07	1.10 ± 0.13

RSR ONLY :	
OFFSET ($Wm^{-2}sr^{-1}$)	GAIN (%)
-0.02 ± 0.07	-1.20 ± 0.12

* Format: PAR ± 95%CL(2σ)

Figure 5. Difference between CERES and CLARREO signals plotted versus CLARREO signal for offset & gain difference (top) and RSR degradation only (bottom). Numbers in corresponding tables show the offset and gain from linear fit. Results with and without matching noise shown in red and green, respectively.

Offset = 0.1 $Wm^{-2}sr^{-1}$, Gain = 1% & RSR Degradation
CLARREO nadir-only sampling:



OFFSET + GAIN + RSR :		
Noise (%)	OFFSET ($Wm^{-2}sr^{-1}$)	GAIN (%)
0.0	0.08 ± 0.003	-0.27 ± 0.01
1.0	0.08 ± 0.07	-0.20 ± 0.13
2.0	0.07 ± 0.14	-0.15 ± 0.25

* 2% Matching noise does not meet accuracy requirement

* Format: PAR ± 95%CL(2σ)

Figure 6. Difference between CERES and CLARREO signal plotted versus CLARREO signal for offset & gain & RSR degradation with matching noise 1% (top) and 2% matching noise (bottom). Numbers in table on the right show the offset and gain from linear fit for noise levels of 0%, 1% and 2%. Simulation results without matching noise are shown in green.

Offset = 0.1 $Wm^{-2}sr^{-1}$, Gain = 1%, Noise σ = 1%
sampling with CLARREO pointing ability
N match = 25,435 FOV :

OFFSET + GAIN ONLY :	
OFFSET ($Wm^{-2}sr^{-1}$)	GAIN (%)
0.11 ± 0.02	0.99 ± 0.04

RSR ONLY :	
OFFSET ($Wm^{-2}sr^{-1}$)	GAIN (%)
-0.01 ± 0.02	-1.27 ± 0.04

OFFSET + GAIN + RSR :		
Sample (FOV)	OFFSET ($Wm^{-2}sr^{-1}$)	GAIN (%)
665	0.08 ± 0.07	-0.20 ± 0.13
25,435	0.09 ± 0.02	-0.29 ± 0.04

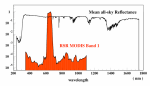
* Noise reduction by averaging in 1.0 $Wm^{-2}sr^{-1}$ bins, N > 100 FOV

* Format: PAR ± 95%CL(2σ)

Summary for CLARREO/CERES Inter-Calibration

- For all-sky case and given set of parameters and sampling the CLARREO/CERES inter-calibration is a linear problem.
- Uncertainty of inter-calibration is dominated by contribution from matching noise. 2% matching noise does not meet accuracy requirement.
- To separate effects from OFFSET/GAIN and the RSR degradation the clear-sky scenes should be studied: CERES RSR degradation produces additional offset and noise for clear sky ocean footprints while DDC/marine stratus footprints are not sensitive.
- Large sampling allows to reduce uncertainty (2σ) of OFFSET to 0.02 $Wm^{-2}sr^{-1}$ and of GAIN to 0.035%.

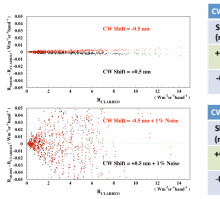
5. Simulation of CLARREO/MODIS Calibration



MODIS Band 1, 620 – 670 nm

Figure 7. Relative spectral response (RSR) of MODIS band 1 (red) and mean all-sky SCIAMACHY nadir reflectance spectrum for 2006.07.01.

Band 1: 0.5 nm CW Shifts, Nadir-only Sampling, 1% Noise

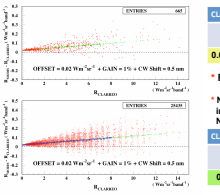


CW SHIFT ONLY :		
Shift (nm)	OFFSET ($Wm^{-2}sr^{-1}$)	GAIN (%)
+0.5	8.8e-04 ± 1.3e-04	-0.03 ± 3.1e-05
-0.5	-7.7e-04 ± 1.3e-04	0.03 ± 3.1e-05

CW SHIFT + NOISE = 1%		
Shift (nm)	OFFSET ($Wm^{-2}sr^{-1}$)	GAIN (%)
+0.5	-0.2e-03 ± 5.0e-03	0.03 ± 0.12
-0.5	-0.3e-03 ± 5.0e-03	0.09 ± 0.12

Figure 8. Difference between MODIS band 1 and CLARREO signals plotted versus CLARREO signal for CW shifts of 0.5 nm only (top), and CW shifts together with 1% matching noise (bottom). Numbers in corresponding tables show the offset and gain from linear fit.

Band 1: 0.5 nm CW Shift, Gain 1% , Offset 0.02 $Wm^{-2}sr^{-1}band^{-1}$
1% Noise, nadir-only and pointing samples



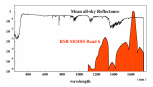
CLARREO Nadir = 665 FOV	
OFFSET ($Wm^{-2}sr^{-1}$)	GAIN (%)
0.0198 ± 0.0051	1.03 ± 0.12

* Format: PAR ± 95%CL(2σ)

* Noise reduction by averaging in 0.15 $Wm^{-2}sr^{-1}band^{-1}$ bins, N >100 FOV.

CLARREO Pointing = 25,435 FOV	
OFFSET ($Wm^{-2}sr^{-1}$)	GAIN (%)
0.021 ± 0.001	0.960 ± 0.024

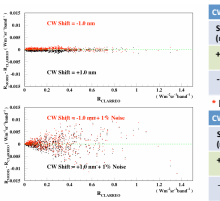
Figure 9. Difference between MODIS band 1 and CLARREO signals plotted versus CLARREO signal for CW shift of 0.5, gain 1%, offset 0.02 $Wm^{-2}sr^{-1}$ difference and matching noise of 1%. TOP: CLARREO nadir-only sampling, BOTTOM: CLARREO pointing sampling. Numbers in corresponding tables show the offset and gain from linear fit.



MODIS Band 6, 1628 – 1652 nm

Figure 10. Relative spectral response (RSR) of MODIS band 6 (red) and mean all-sky SCIAMACHY nadir reflectance spectrum for 2006.07.01.

Band 6: 1.0 nm CW Shifts, Nadir-only Sampling, 1% Noise



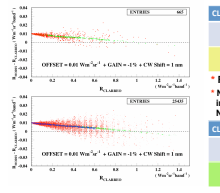
CW SHIFT ONLY :		
Shift (nm)	OFFSET ($Wm^{-2}sr^{-1}$)	GAIN (%)
+1.0	-3.6e-04 ± 0.4e-04	0.011 ± 0.013
-1.0	4.1e-04 ± 0.5e-04	-0.048 ±0.015

* Format: PAR ± 95%CL(2σ)

CW SHIFT + NOISE = 1% :		
Shift (nm)	OFFSET ($Wm^{-2}sr^{-1}$)	GAIN (%)
+1.0	-4.8e-04 ± 3.4e-04	0.11 ± 0.11
-1.0	2.9e-04 ± 3.4e-04	0.05 ± 0.11

Figure 11. Difference between MODIS band 6 and CLARREO signals plotted versus CLARREO signal for CW shifts of 1.0 nm only (top), and CW shifts together with 1% matching noise (bottom). Numbers in corresponding tables show the offset and gain from linear fit.

Band 6: 1 nm CW Shift, Gain -1% ,Offset 0.01 $Wm^{-2}sr^{-1}band^{-1}$
1% Noise, nadir-only and pointing samples



CLARREO Nadir = 665 FOV	
OFFSET ($Wm^{-2}sr^{-1}$)	GAIN (%)
0.0095 ± 0.0003	-0.89 ± 0.11

* Format: PAR ± 95%CL(2σ)

* Noise reduction by averaging in 0.01 $Wm^{-2}sr^{-1}band^{-1}$ bins, N >100 FOV.

CLARREO Pointing = 25,435 FOV	
OFFSET ($Wm^{-2}sr^{-1}$)	GAIN (%)
0.0096 ± 0.00012	-0.990 ± 0.035

Figure 12. Difference between MODIS band 6 and CLARREO signals plotted versus CLARREO signal for CW shift of 1.0, gain -1%, offset 0.01 $Wm^{-2}sr^{-1}$ difference and matching noise of 1%. TOP: CLARREO nadir-only sampling, BOTTOM: CLARREO pointing sampling. Numbers in corresponding tables show the offset and gain from linear fit.

Summary for CLARREO/MODIS Inter-Calibration

- For selected bands Inter-calibration uncertainty is dominated by contribution from matching noise.
- Effects from RSR central wave shifts below 1 nm are very small for MODIS bands 1, 2 and 6.
- Simulation is not sensitive to spectral shifts below the resolution → CLARREO resolution
- CLARREO basic scene ID is needed for studying non-linear effects due to RSR degradation.
- Depending on band, large sampling reduces uncertainty from offset/gain factor 2-3.